Maintaining image quality in VQ SPECT

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Background
During 2015 and 2016, 50,696 admissions for acute pulmonary embolism were reported in the UK alone, resulting in an incidence of around 0.8 per 1,000 population. Just under 10% of these cases were in patients aged 40 or under; a cohort with greater than the reported 0.005% per mSv average lifetime cancer risk. While VQ scintigraphy is generally considered a low dose procedure (up to 2.8mSv for the maximum ARSAC diagnostic reference level (DRL) for 99mTc based radionuclides), the requirement for dose optimisation while maintaining diagnostic image quality still remains.

Despite first appearing in the literature just before the publication of the widely implemented PIOPED criteria for interpretation of planar lung imaging, SPECT imaging for pulmonary embolism has only relatively recently become routine practice. VQ SPECT is now explicitly mentioned in NICE guidelines (CG144) as an alternative to CT pulmonary angiography for patients who have an allergy to contrast media, renal impairment or whose risk from irradiation is high. This is supported by a recent meta-analysis that demonstrated no significant difference between the diagnostic accuracy of VQ SPECT and CTPA; with the former being more efficient in terms of radiation dose and the latter only in terms of financial cost.

Administered activities
For 99mTc based radiopharmaceuticals, the European Association of Nuclear Medicine guidelines for ventilation/perfusion scintigraphy recommend 20-30MBq of 99mTc ventilation agents and 40-120MBq 99mTc-MAA for perfusion imaging. This is lower than the ARSAC DRL for SPECT imaging, approximately 12 minutes for perfusion and 15-20 minutes for ventilation. In the often-quoted study by Palmer et al, the increased resolution of the LEHR collimators was found to have little additional value over the higher sensitivity low-energy all-purpose (LEAP) collimators in phantom studies, and have been used by several authors in the literature.

While perfectly acceptable image quality was found with the higher count rate perfusion administration, we found that the reconstructed ventilation image quality was initially an issue and at times the images were too noisy for interpretation, mainly due to inadequate count statistics in the acquired data and the consequences of variable patient anatomy. We therefore developed a scheme for maintaining the noise level of our reconstructed ventilation images.

Estimating noise levels
The noise in a scintigraphic image reflects the statistical variation arising from the random fluctuations in emissions from radioactive decays. For the planar projections this is well known and can be described by Poisson statistics. In images reconstructed using an expectation-maximisation algorithm (such as MLEM, OSEM), however, the uncertainty at each pixel value due to noise is more complex as it is updated in a multiplicative way throughout several iterations.

We developed a technique (presented at BNMS 2016) to give a figure-of-merit for the reconstructed images that was indicative of noise, irrespective of the underlying activity distribution. We called this figure-of-merit the two-sample coefficient of variation (2SCoV). To assess the validity and applicability of the technique, three observers were presented 190 pairs of reconstructed ventilation images and asked which the noisier image was. The percentage of occasions each was considered the less noisy of the two was plotted against the 2SCoV value (figure 1). There was a clear trend between increasing values of the figure-of-merit and subjective observer rating and hence the figure was used in our future analysis.

Controlling noise in reconstructed SPECT images
The noise level in the reconstructed SPECT images is directly related to the activity concentration in the lungs; as we administer fixed activities the volume of the patient’s lungs is therefore the key determinant. Simple measures of administered activity, such as monitoring the planar count-
rate on the detector during inhalation, only reflect the total activity inhaled by the patient and not activity concentration. These are therefore not completely predictive of resultant noise (Figure 2). We found that the mean count within the lung on the posterior planar projection correlated well with subsequent reconstructed image noise and therefore proposed the acquisition of a short, 15-second, static immediately prior to the SPECT acquisition to inform the subsequent projection time. In practice, the mean lung count is calculated automatically from this pre-SPECT static using an in-house written GE Aladdin (GE Healthcare) program, which provides the operator with the required projection time length.

To find a clinically acceptable noise level we asked our clinicians to provide subjective feedback on the reconstructed image quality; scoring images as acceptable, borderline acceptable and not acceptable. The target mean lung count was then set at two standard deviations above the highest ‘borderline’ case; with the standard deviation derived from the variation in the ‘acceptable’ cases. The processing software uses this information to provide an estimate of the change in projection time required to achieve the target mean lung count, based on a linear scaling. The whole process takes less than 30 seconds and has now become routine practice.

After implementation of the standardisation method, we audited the image quality of the ventilation imaging pre- and post-change. We found that the new method significantly reduced the variation in noise levels, offering greater consistency in image quality (Figure 3). The subsequent imaging times to achieve acceptable image quality range from 14 to 19 seconds per projection, an example of the change in quality is shown in Figure 4.

Follow-up and audit
We recently presented an audit at BNMS 2017 of 343 consecutive patients attending for investigation of pulmonary embolism, including a follow-up period of three to 12 months, during our transitional period. Of these patients, 262 (76.4%) showed no evidence of PE and all had no subsequent attendances or investigations for PE during the follow-up period, giving us confidence that the false negative rate for this protocol is extremely low (95% confidence interval of less than 1%), although this is under repeated audit.

Conclusions
Investigations for pulmonary embolism can be successfully performed using a low-dose regime and LELEG collimators. However, noise levels in the reconstructed ventilation images require the adjustment of the projection times during the SPECT acquisition to compensate for the low activities used. Our proposed method of using a pre-SPECT static has been demonstrated to correlate well with image noise and improve the consistency of image quality in the VQ SPECT imaging.

References

TABLE 1
Selection of administration and acquisition protocols used for VQ SPECT investigations found in the literature.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>Collimator</th>
<th>Matrix</th>
<th>Projections</th>
<th>Perfusion</th>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Le Roux et al</td>
<td>2015</td>
<td>LEHR</td>
<td>128</td>
<td>128</td>
<td>140MBq MAA</td>
<td>81mKr</td>
</tr>
<tr>
<td>Bajc et al</td>
<td>2013</td>
<td>LEAP</td>
<td>64</td>
<td>128</td>
<td>120 MBq MAA</td>
<td>30 MBq 99mTc-DTPA</td>
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<tr>
<td>Gutte et al</td>
<td>2010</td>
<td>LEGP</td>
<td>128</td>
<td>72</td>
<td>150 MBq MAA</td>
<td>81mKr</td>
</tr>
<tr>
<td>Reinartz et al</td>
<td>2004</td>
<td>LEHR</td>
<td>64</td>
<td>64</td>
<td>200 MBq MAA</td>
<td>500 MBq Technegas</td>
</tr>
</tbody>
</table>

Figure 1
Validation of our figure of merit for noise estimation with visual assessment. A clear correlation is seen indicating the 2SCoV can be used as a measure of subjective image quality.
Figure 2
Variation of the noise figure-of-merit with (top) posterior count rate and (bottom) mean of posterior counts generated from a 15-second static. A stronger correlation is seen with the mean count value.

Figure 3
Change in the noise figure-of-merit before and after the change in practice from using posterior count rate to using the pre-SPECT static to inform acquisition times. A clear reduction in the variation of noise is seen, giving rise to more consistent image quality.

Figure 4
Example images showing the effect of standardising to mean lung count (left) rather than posterior count-rate (right). The effective projection times were 19 and 14 seconds respectively; the lower count image was resampled for illustrative purposes.